2014 NEPP Tasks Update for Ceramic and Tantalum Capacitors

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To be presented by A.Teverovsky at the NASA Electronic Parts and Packaging (NEPP) Electronics Technology Workshop, Greenbelt, MD, June 17-19, 2014.

List of Acronyms and Symbols

AF	acceleration factor	**MLCC**	multilayer ceramic capacitor
BME	base metal electrode	**MSL**	Moisture sensitivity level
C	capacitance	**PME**	precious metal electrode
DCL	direct current leakage	**PV**	Prokopowicz-Vaskas
DF	dissipation factor	**S&Q**	screening and qualification
DWV	dielectric withstanding voltage	**STD**	Standard deviation
ESR	Equivalent series resistance	**T**	temperature
HALT	highly accelerated life testing	**THB**	temperature, humidity, bias
HSSL	humidity steady state low voltage	**TSD**	terminal solder dip
HT	High temperature	**TTF**	time to failure
HV	high voltage	**VBR**	breakdown voltage
IM	Infant mortality	$\mathbf{VBR_{75}}$	third quartile of VBR distribution
IR	insulation resistance	$\mathbf{V_O^{++}}$	charged oxygen vacancy
LV	low voltage	**VR**	rated voltage

Outline

- Update on tantalum capacitors.
  - MnO_2 chip capacitors.
  - Advanced wet capacitors.
  - Polymer capacitors.
  - Future work.
- Update on ceramic capacitors.
  - Low-voltage failures in MLCCs.
  - IR degradation of BME capacitors caused by oxygen vacancies.
  - The significance of breakdown voltages for quality assurance of BME capacitors.
  - Effect of soldering.
  - Future work.

Diversity of Tantalum Capacitors

Technologies similar to Ta:
Nb/Nb2O5 and NbO/Nb2O5

New Technology Tantalum Capacitors

Specifications:
military, SCD, medical, automotive

- **MnO_2**
  - KEMET F-process
  - AVX Q-process
  - Low ESL, multianode, stacked, …
  - microchips
  - embedded
- **Wet**
  - SuperTan, TWA
  - Hybrid
  - Supercapacitors
- **Polymer**
  - LV molded chips
  - HV molded chips
  - Hermetically sealed

✓ Diversity is due to the variety of cathode systems.
✓ A general trend: reduction of size and ESR, increase in C, VR, and T_{oper}.
✓ New technologies appear with increasing speed.

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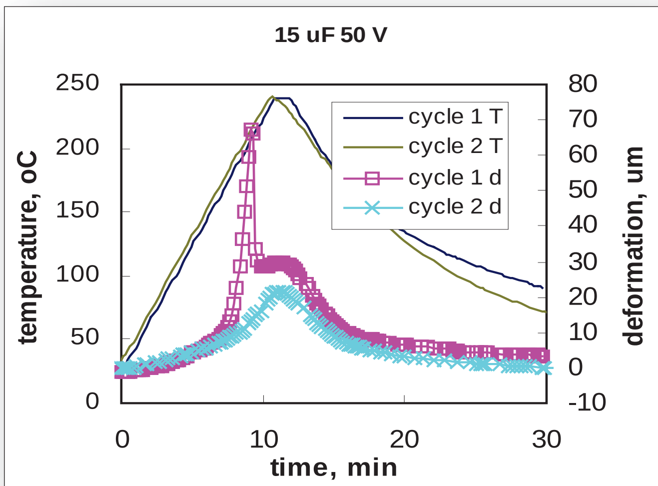
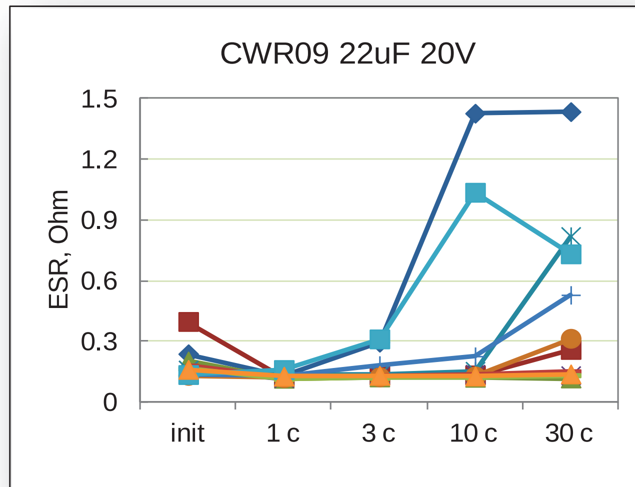
Updates on MnO_2 Tantalum Capacitors

- ❑ Projects problems with capacitors appear with ~constant rate.
- ❑ Deficiencies in M55365 and new screening processes are in line with NEPP recommendations.
  - KEMET F-technology – importance of VBR.
  - AVX Q- technology – Weibull grading, HT DCL, reflow…
- ❑ Pop-corning and MSL.



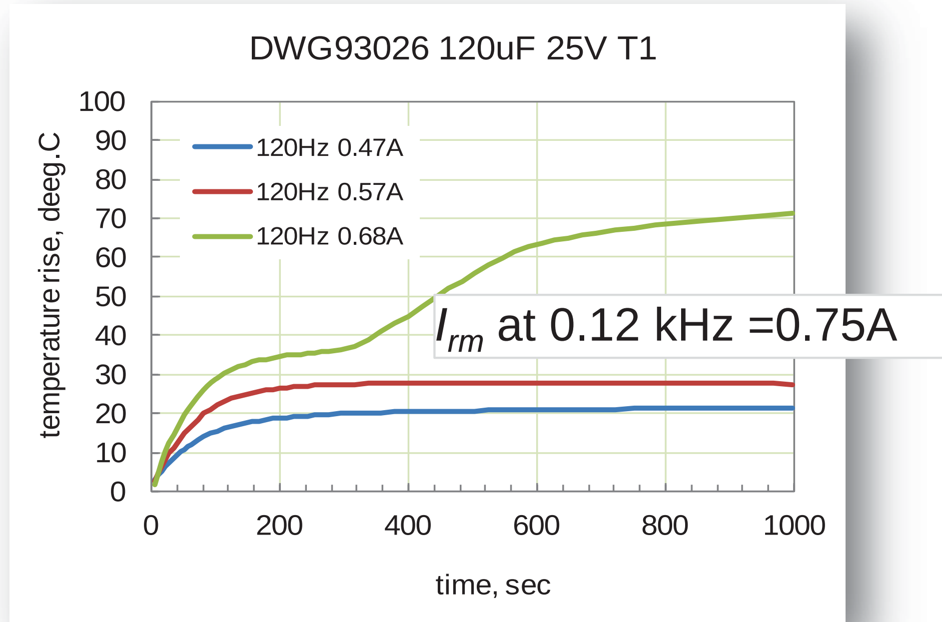


✓Baking to avoid pop-corning.
✓Multiple soldering cycles might degrade ESR and DCL.
✓Recent projects' failures (linear regulator oscillated due to increased ESR, first turn-on failures)

Updates on Wet Tantalum Capacitors

- Reverse bias effects are similar to solid tantalum capacitors but might cause more dramatic consequences.
- Ripple current testing and requirements for rating and derating for applications in vacuum.
- Vibration testing of various types of capacitors is work in progress.

Failure in vacuum chamber



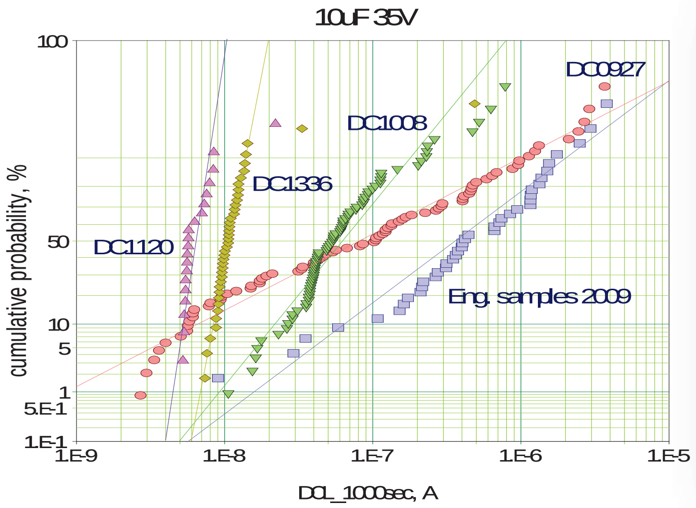
Thermal run-away in vacuum happened at currents below I_{rm}.

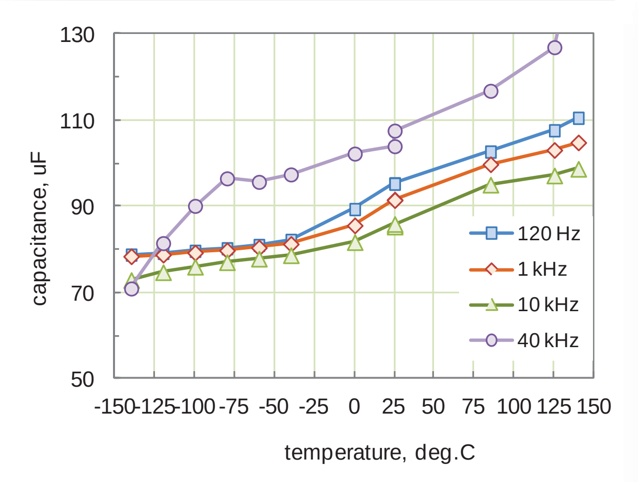
✓ Guidelines for S&Q have been updated to include ripple current requirements.

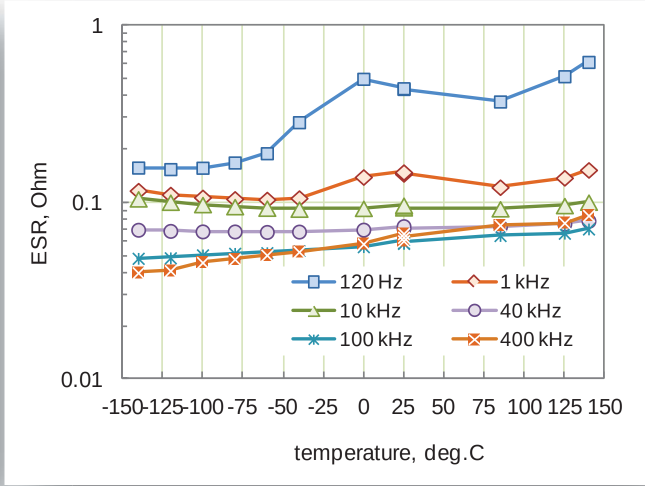
✓ Requirements for vibration testing should be specified.

Updates on Polymer Capacitors

- Characteristics of various types of chip and hermetic polymer tantalum capacitors are monitored since 2009.
- Substantial progress in performance and quality, especially for HV capacitors.

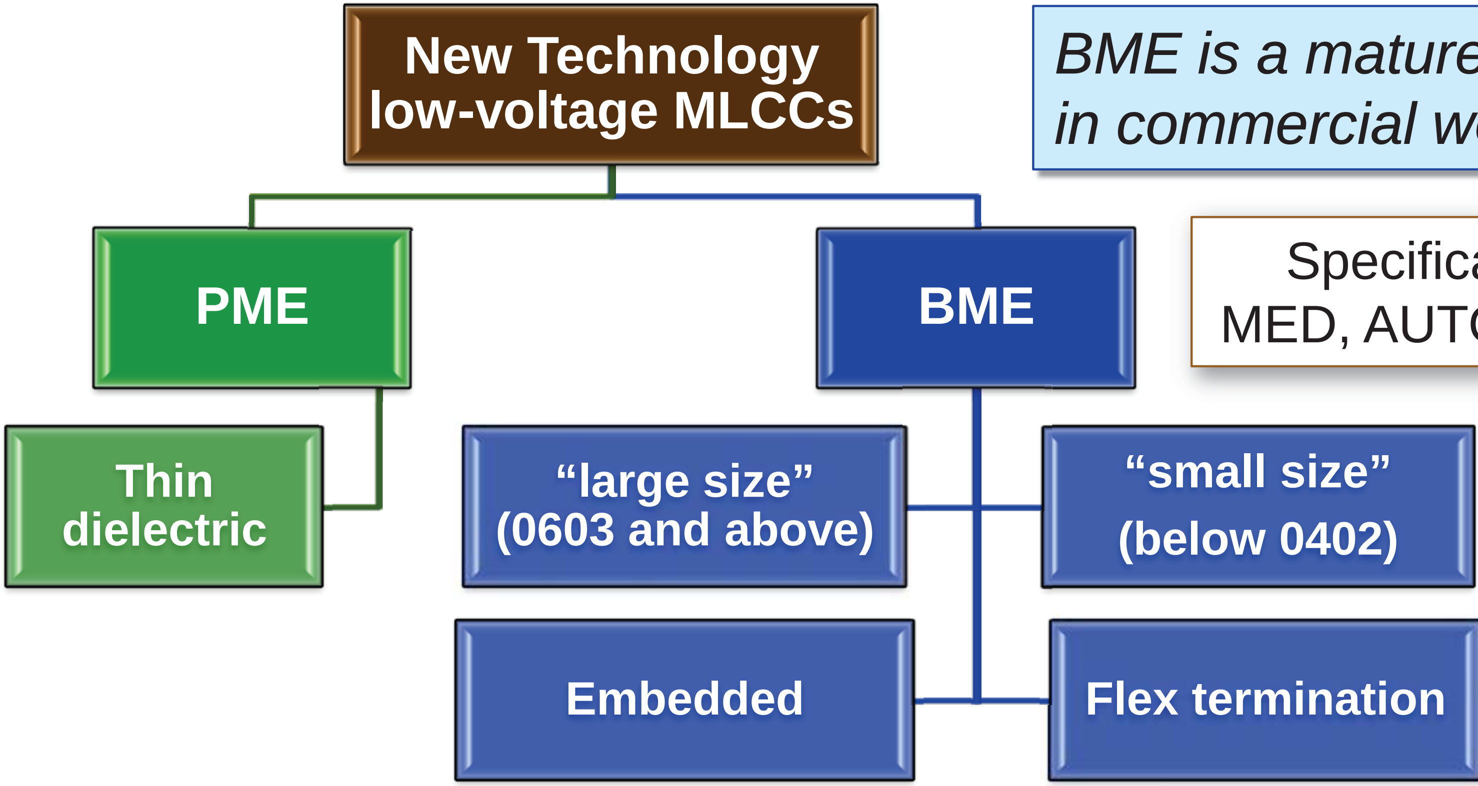






- Chip capacitors are still not ready for space applications.
- Hermetically sealed capacitors are good candidates for space, especially for low-temperature applications.
- High-temperature performance still remains a problem.

New Technology MLCCs

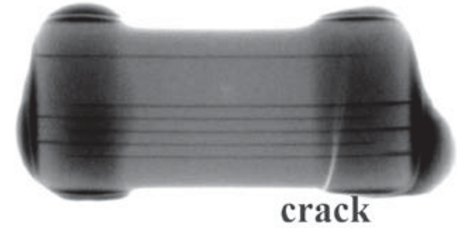


BME is a mature technology in commercial world

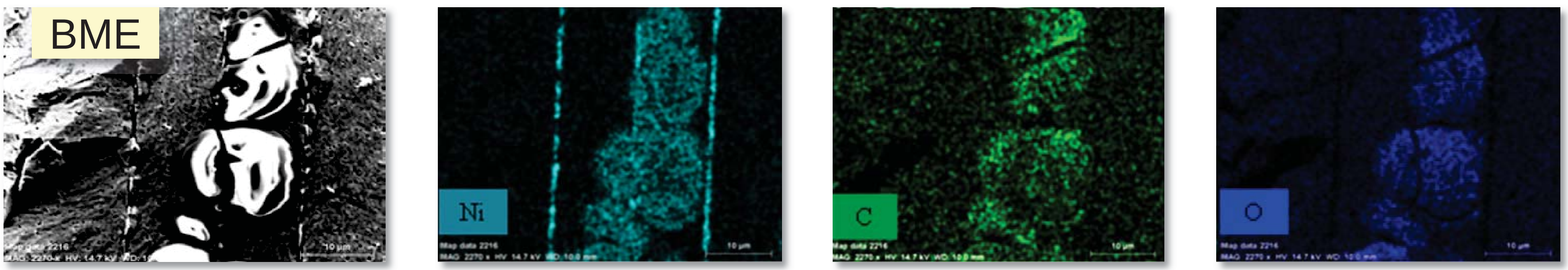
Specifications: MED, AUTO, MIL(?)

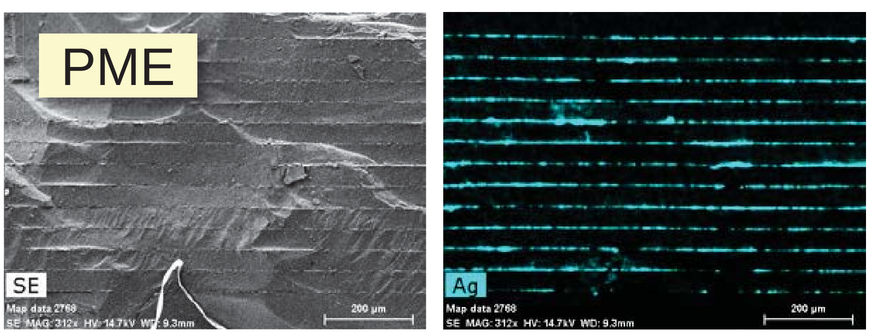
- The electrode system in MLCCs is limited to two materials.
- Diversity is due to variety of ceramic compositions and processes.
- Two major issues with MLCC:
  - Cracking-related low-voltage failures;
  - Oxygen-vacancies-related IR degradation.

Low-Voltage Failures



- HSSLV testing of various types of PME and BME capacitors showed that all PME capacitors with cracks failed, compared to16% for BME.
- Failed BME capacitors had much greater IR.
- Cracks in BME can be revealed by THB testing at V >> 1.3V.
- Manual soldering have a detrimental effect on MLCCs with defects.





- Probability of failures for PME is greater than for BME capacitors.
- The difference is due to the specifics of electro-chemical behavior of Ni and Ag/Pd and formed products.
- HSSLV testing is not effective for BME.

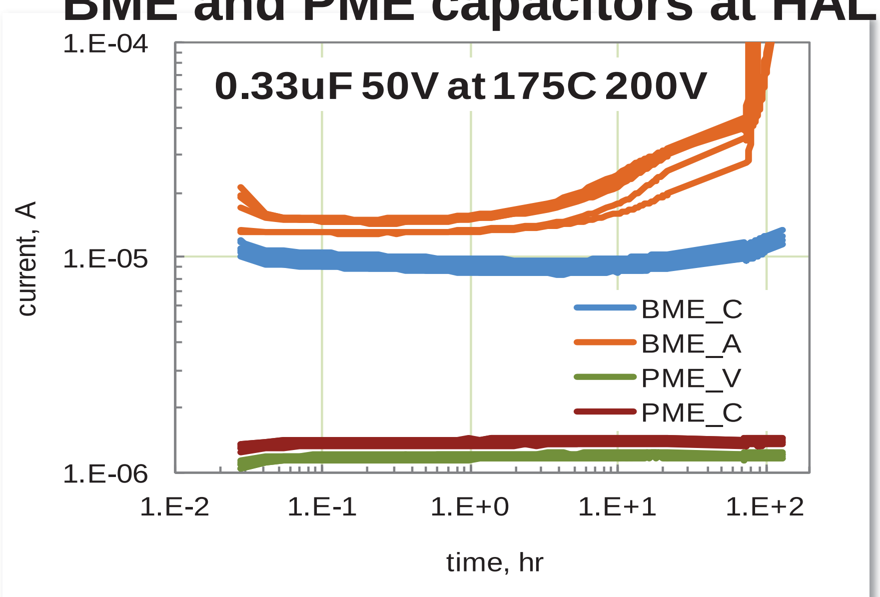
IR Degradation

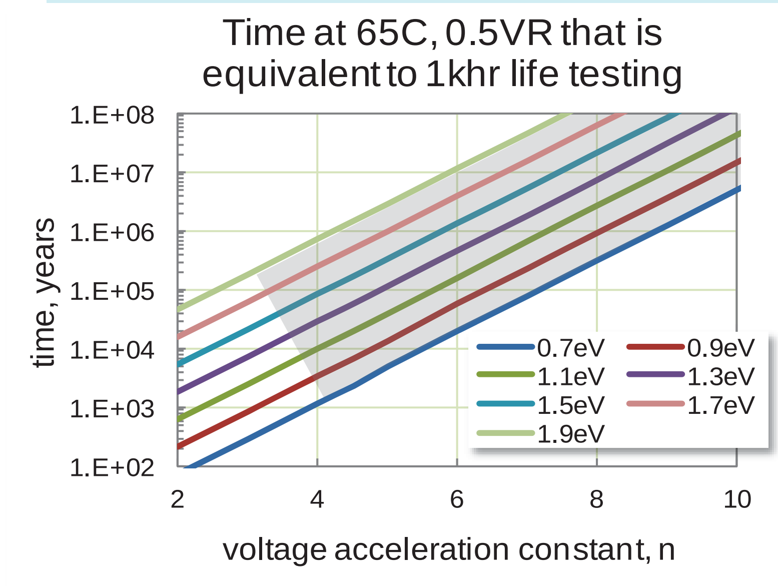
- It is assumed that reliability of BMEs is limited by V_O^{++}.
- The wear-out problem is still there, but it has been moved out of application conditions by using new materials and processes.

(Life testing (1000 hr, 2VR, 125 °C) is equivalent to thousands of years at 65 °C and 0.5 VR).

$$AF = \left(\frac{V_2}{V_1}\right)^n \times \exp\left[\frac{E_a}{k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

BME and PME capacitors at HALT



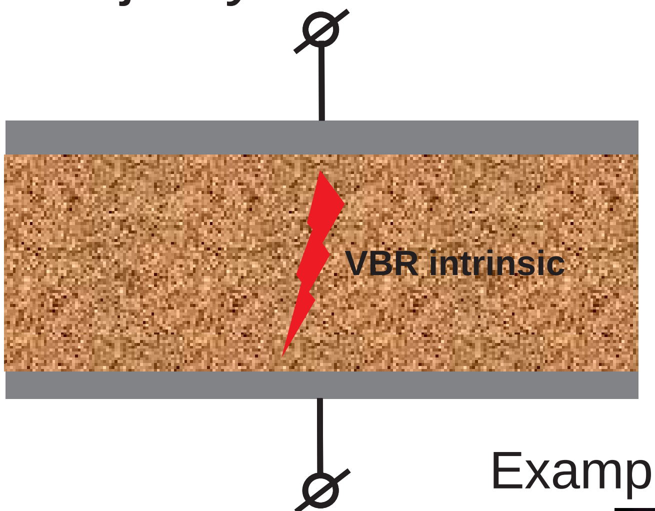


- Intrinsic wear-out failures due to V_O^{++} do not affect applications.
- Failures in the systems are caused by manufacturing or assembly-introduced defects.

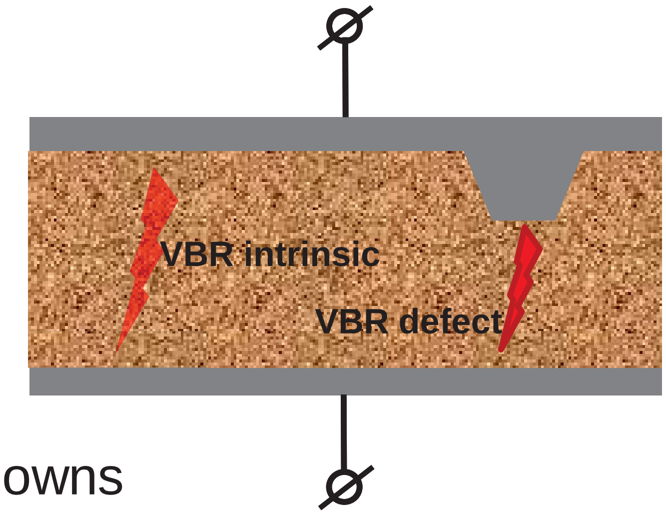
T... (CARTS) conference, Santa Clara, California, April 1-3, 2014.

Detection of Defects

- Local defects do not change C, DF and IR, but affect VBR.
- Majority of MLCCs with defects can pass DWV test.



$VBR_i < VBR_d$

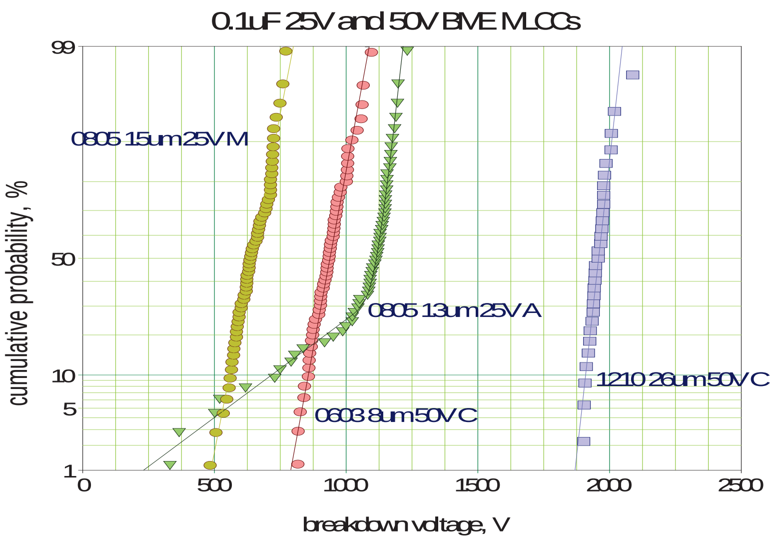


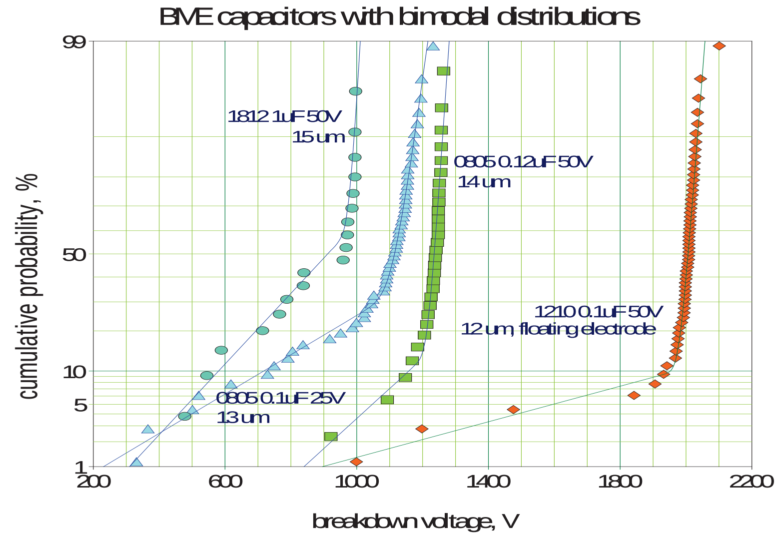
Example of intrinsic breakdowns

- ✓ High values of VBR (similar to IR) provide assurance that the parts have no gross defects that might cause failures.
- ✓ The consistency of VBR distributions indicates stability of the manufacturing process and quality of the product.

Distributions of VBR

- In most cases distributions of VBR for BME capacitors are bimodal.
- The HV mode has tight distributions (STD/Mean ~4%) indicating intrinsic breakdown.
- The presence of LV subgroup is due to defects.

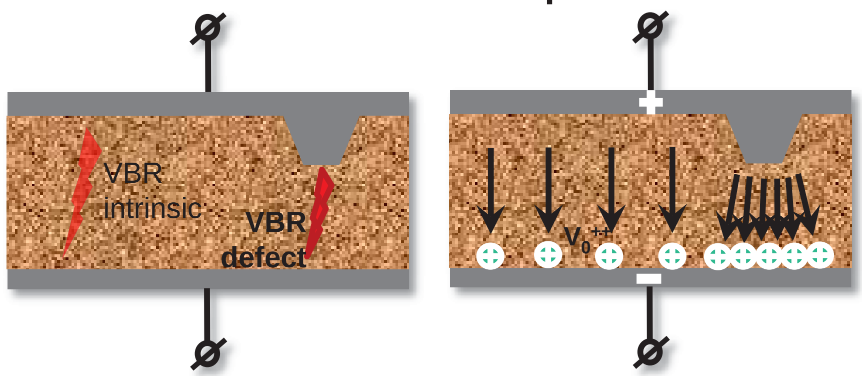




- ✓ The interception point indicates proportion of defects.
- ✓ The spread of VBR towards low voltages indicates the significance of defects.
- ✓ Lot acceptance criterion: $VBR_{min}/VBR_{75} > 0.5$.

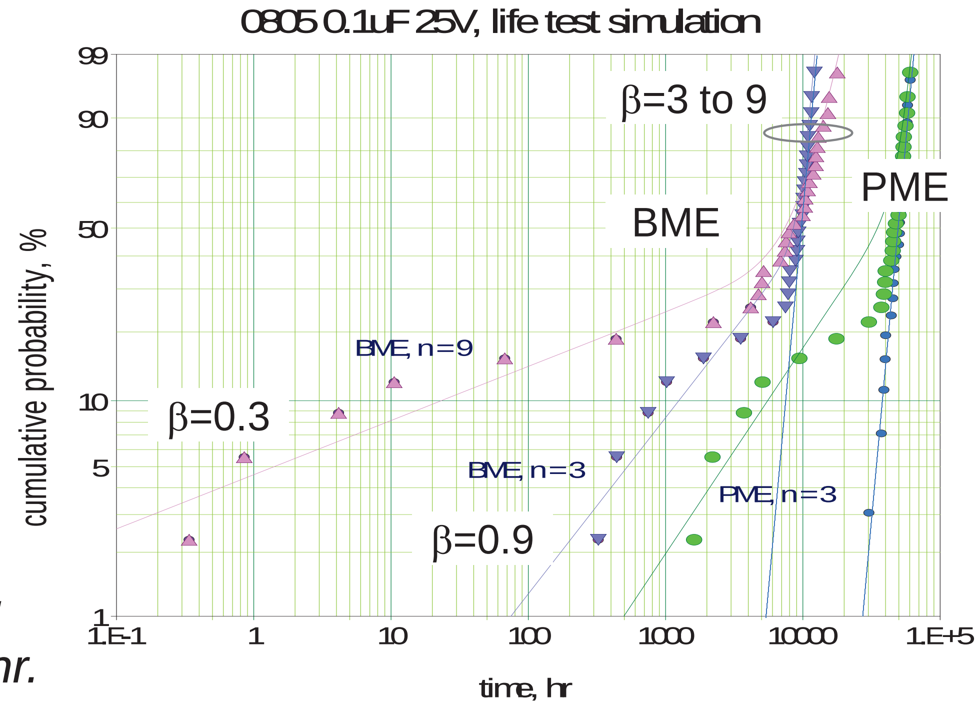
Reliability of MLCCs with Defects

Assumptions: intrinsic degradation for a defect-free part results in failures at TTF_0 and the voltage AF follows PV equation with *n* ~ 3 for PME and *n* from 4 to 9 for BME capacitors.



$$TTF = TTF_0 \times \left(VBR_d / VBR_i \right)^n$$

TTFs were calculated based on VBR assuming for PME TTF_0=50 khr, and for BME TTF_0=10 khr.



- ✓ Wear-out degradation in BME capacitors with defects results in IM failures.
- ✓ The greater the voltage acceleration constant *n* and the lower VBR/VBR_{75}, the more probable IM failures are.

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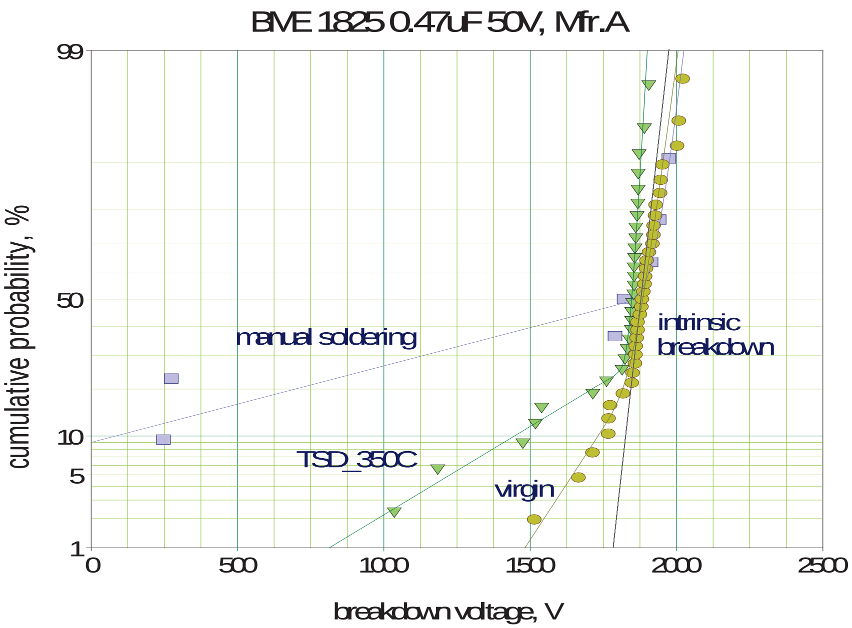
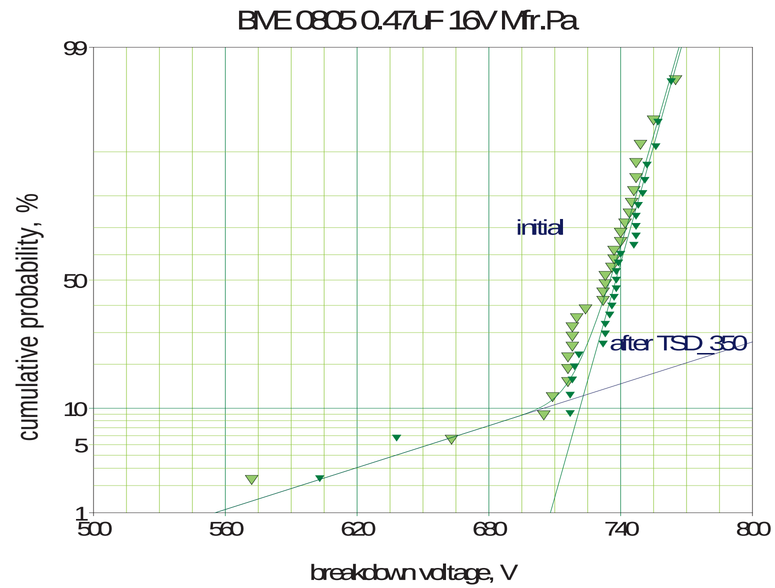
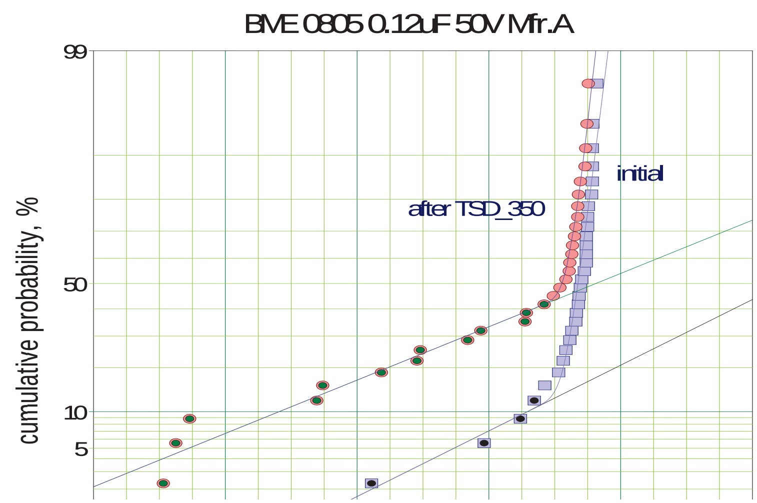
Effect of Soldering Stresses on VBR



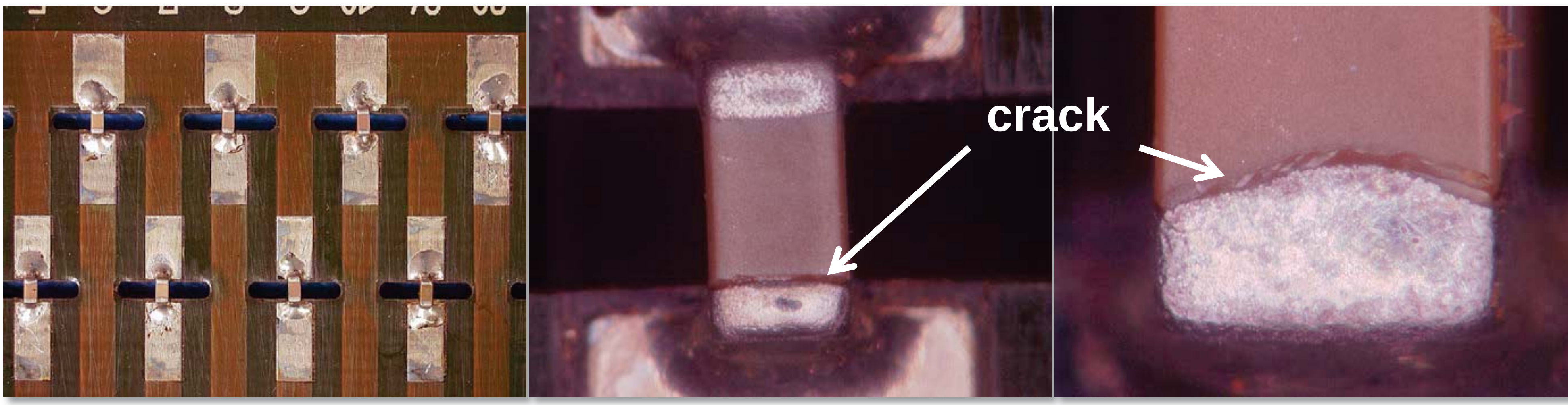




- ✓Some lots are sensitive to TSD stress.
- ✓Stresses related to manual soldering can degrade VBR.
- ✓VBR can be used as one of tests to qualify MLCCs for manual soldering.

Effect of Soldering

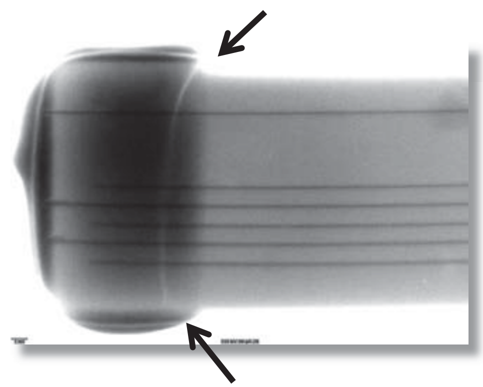
- It is often assumed that large size MLCCs are more vulnerable to cracking.
- Out of 40 samples of 0603 size MLCCs soldered with a soldering iron set to 315°C, 10 samples had intermittent or no contact.
- Failures were due to cracks along the terminations.
- No failures when parts were soldered onto a board preheated to 150°C.



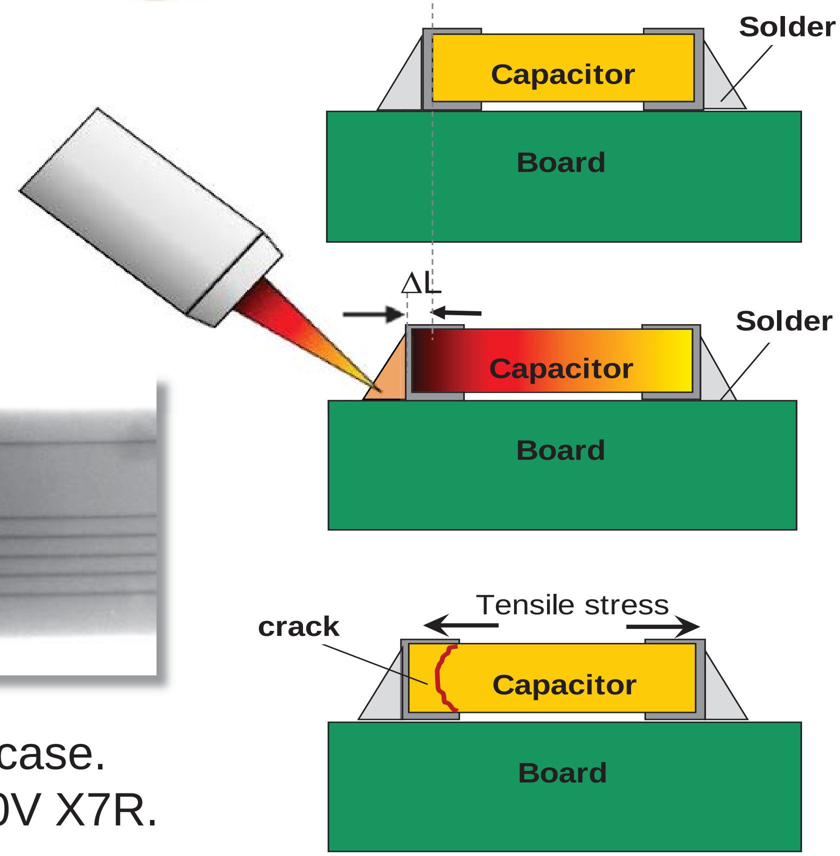
- ✓ Manual soldering can cause cracking of small size capacitors.
- ✓ Preheating of the board is critical to reduce the probability of failures.

Effect of Soldering, Cont'd

- ❑ Post-soldering touch-up to improve the attachment might result in tensile stresses.
- ❑ Tensile stresses can cause cracking.



Project failure case.
0402, 1000pF 50V X7R.



✓ To decrease the probability of fracturing during soldering, both, the reduction of the level of stress and selection of robust capacitors are necessary.

Future Work on Ceramic Capacitors

- Defect-related mechanism of failures at HT.
  - *Requirements for screening.*
- Effect of manual soldering conditions on reliability.
  - *Requirements for qualification testing*.
- Comparative analysis of performance and reliability of PME and BME capacitors:
  - Leakage currents.
  - Breakdown voltages.
  - Mechanical characteristics and the probability of fracturing.
  - *Recommendations for application.*
- Reliability issues related to assembly of small size MLCCs (0402 and less).
  - *Screening and qualification requirements.*